

Space Physiology and Operational Space Medicine

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Terminal Learning Objective

ACTION: Understand physiological effects of micro- and partial gravity on the human body and the operational space medicine environment.

CONDITION: While serving as a flight surgeon in support of space operations

STANDARD: IAW The Fundamentals of Aerospace Medicine, Fundamentals of Space Medicine, and the current Space Medicine Literature

Enabling Learning Objectives

- Be familiar with the effects of short- and long-duration space flight on the human body
- Be familiar with the major medical concerns regarding future long duration missions
 - Be familiar with the available countermeasures for these effects
- Be familiar with the environmental issues that have potential medical impact on the crew
- Be familiar with the role and capabilities of the Space Medicine Flight Surgeon
- Be familiar with the environmental impacts experienced by the Apollo crews

Physiological effects of Short- and Long Duration Space Flight on the Human Body

- **Space Motion Sickness (SMS)**
- **Neurovestibular**
- **Cardiovascular**
- **Musculoskeletal**
- **Immune/Hematopoietic system**
- **Behavioral/Psycho-social**

Space Motion Sickness (SMS)

Space Motion Sickness (SMS)

- Incidence
 - Affects approximately 66-95% of all crewmembers
 - 10% of cases are severe
- Symptoms
 - From loss of appetite to nausea and vomiting
- Time Course
 - Onset from MECO to 24 hours; peak symptoms at 24 to 48 hours; symptoms resolve at 72 to 96 hours

Space Motion Sickness (SMS)

- The possible causes of SMS:
 - Relationship between orientation illusions and SMS
 - Influence of otolith organs asymmetry
 - Sensori-motor conflict
- Fluid shift

Space Motion Sickness (SMS)

- A reliable and validated predictor of SMS :
 - Susceptibility to SMS is not correlated with susceptibility to motion sickness on Earth
 - Preflight Adaptation Training (PAT) promising, but for research only (requires voluntary consent)
 - The problem is generally brought on by head movements in pitch and roll

Space Motion Sickness Categorization

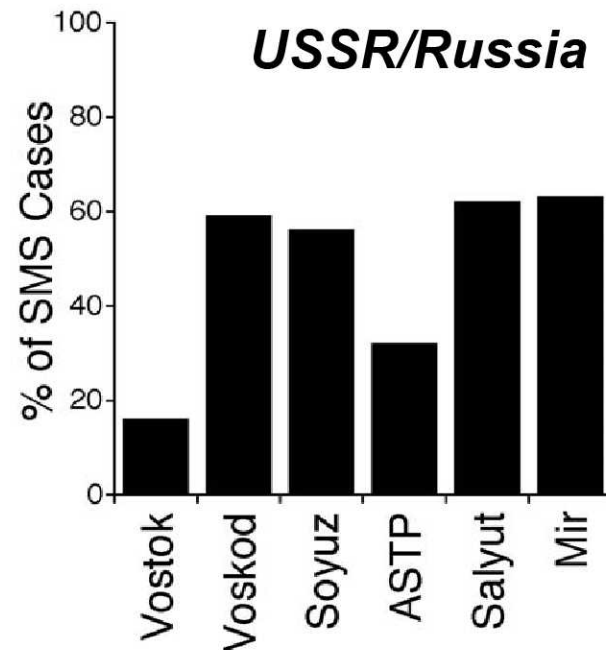
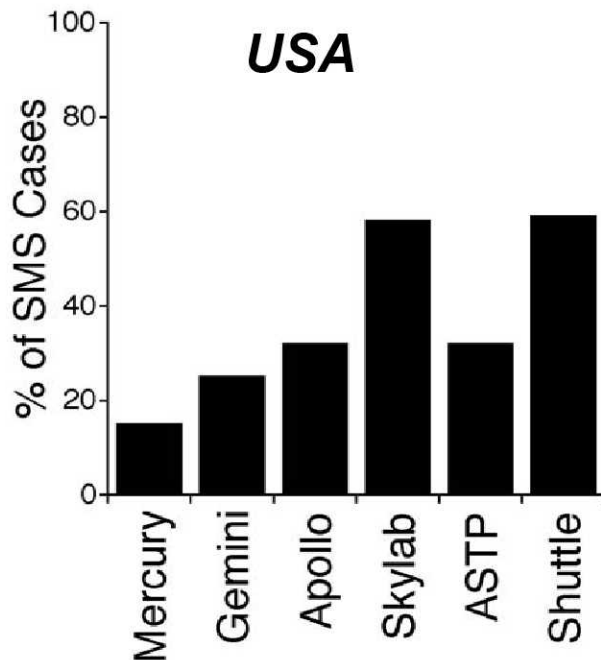
- **Mild SMS:**

- One to several transient symptoms
- No operational impact
- All symptoms resolved in 36-48 hrs

- **Moderate SMS:**

- Several symptoms of a persistent nature
- Minimal operational impact
- All symptoms resolved in 72 hrs

- **Severe SMS:**



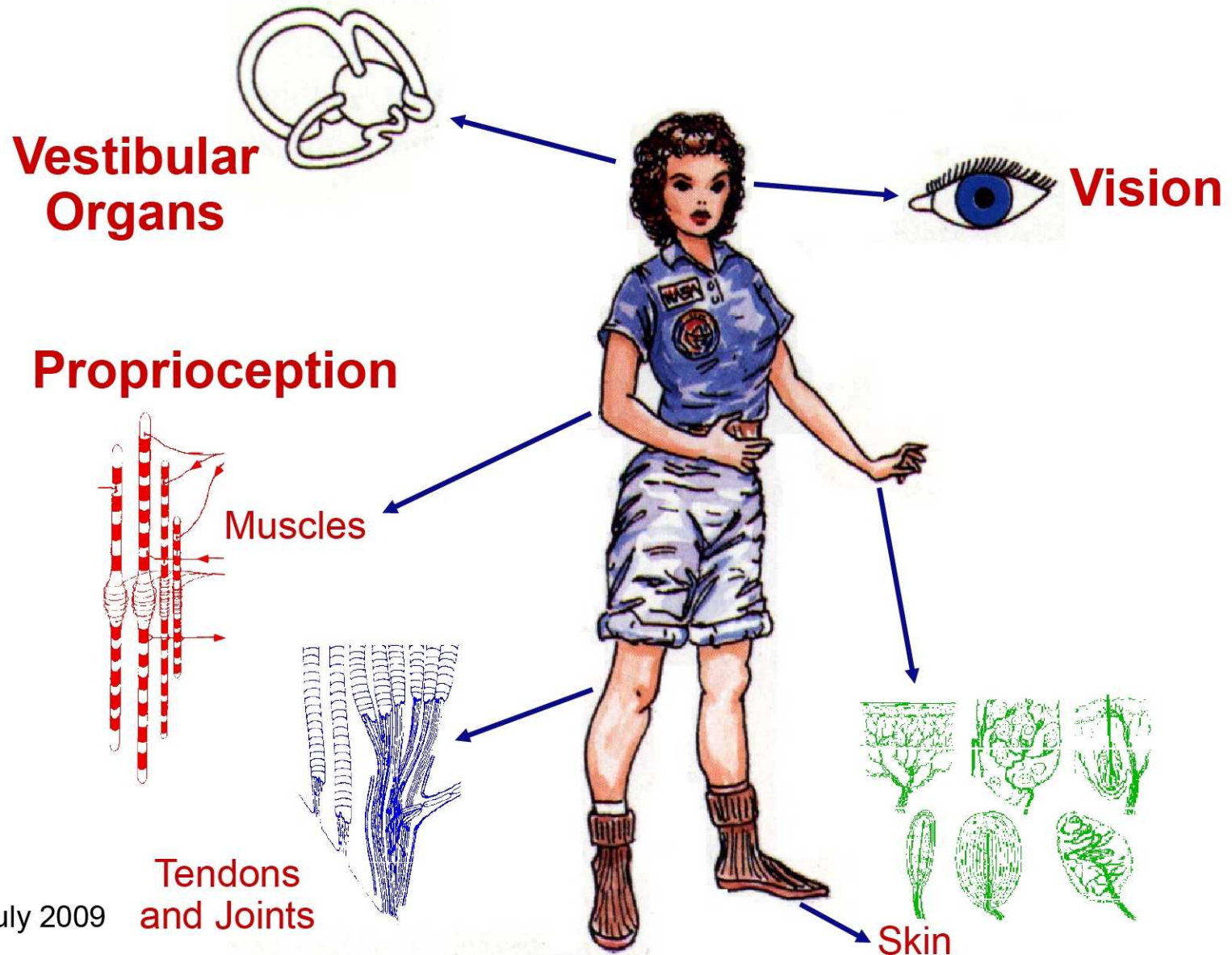
Space Motion Sickness (SMS)

- Treatment
 - The current favorite drug treatment is 25 mg-50 mg IM injection of promethazine
 - rather than the use of scopolamine or other prophylactic medications
 - the side effects of promethazine

Space Motion Sickness (SMS)

- Treatment *cont'd...*
 - Inactivity
 - 1-G orientation
 - Preflight Training and Prophylaxis

The Sense of Motion



Neurovestibular

In-flight changes in neural feedback function that produce postural imbalance and loss of coordination post flight

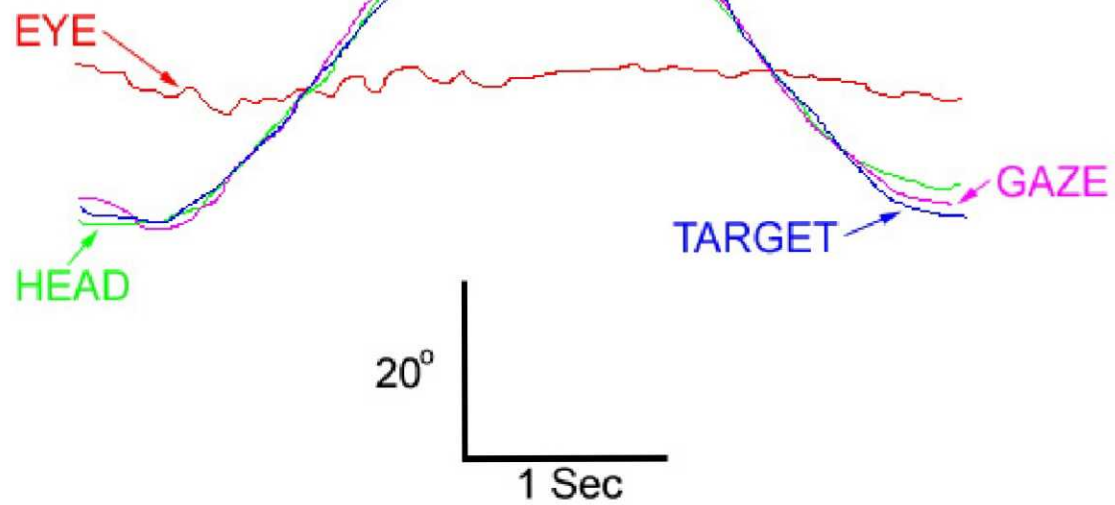
- **Incidence** - All crewmembers are affected to some degree
- **Symptoms** - From vertigo and unstable gait to nausea and vomiting
- **Time course** - From landing to 48 - 72 hours postlanding
- **Causes** - Neurovestibular-otolith and proprioception readaptation

Oman, C.M. and Balkwill, M.D. *Horizontal angular VOR, nystagmus dumping, and sensation duration in Spacelab SLS-1 crew members*. Journal of Vestibular Research, Vol 3, 1993;315-330.

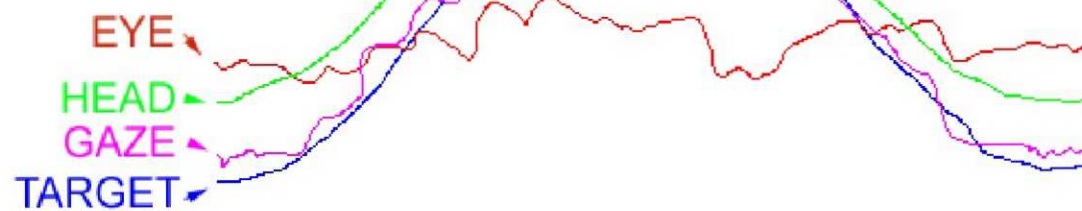
Young L.R., Oman C.M., Merfeld D., Watt D., Roy S. DeLuca C, Balkwill D., Christie J. Groleau N. Jackson D.K., Law G. Modestino S. Mayer W. *Spatial orientation and posture during and following weightlessness: human experiments on Spacelab Life Sciences 1*. J. Vest. Res, 1993.

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Physiological Events and Piloting

Landing performance:

- Initial apparent correlation of length of shuttle mission and landing outside or nearly outside parameters (landing too fast, landing too slow, landing hard)
- Upon further study, correlation not verified (however, there was one very short mission that had bad landing parameters that may have skewed the data considering the small number of data points)
- What is verified is that actual landing performance shows much greater variability than simulator performance parameters
- The implication is that spaceflight has an effect on pilot performance- and now is correlating with post-flight **neurovestibular** measures

Lunar Surface Operations

- Crews generally felt a little “wobbly” upon stepping on the moon
 - Coordination seemed to improve steadily during first couple of hours on the surface
 - Crews denied problems with spatial disorientation on lunar landing

Effects on the Heart:

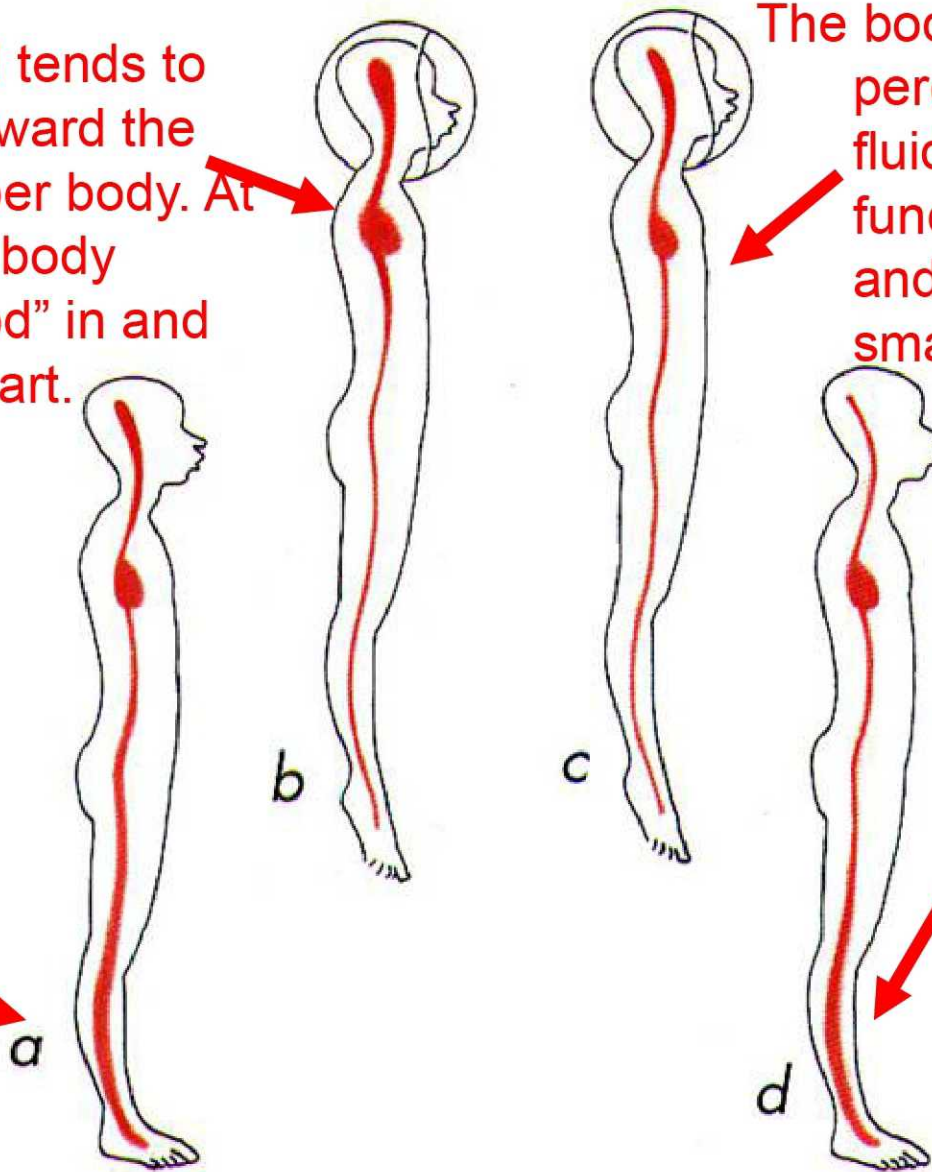
Pre-Flight

- Fluid shift begins while sitting on launch pad-reclined position for long period.

Fluid Shifts during Space Flight

In space, the fluid tends to redistribute toward the chest and upper body. At this point, the body detects a “flood” in and around the heart.

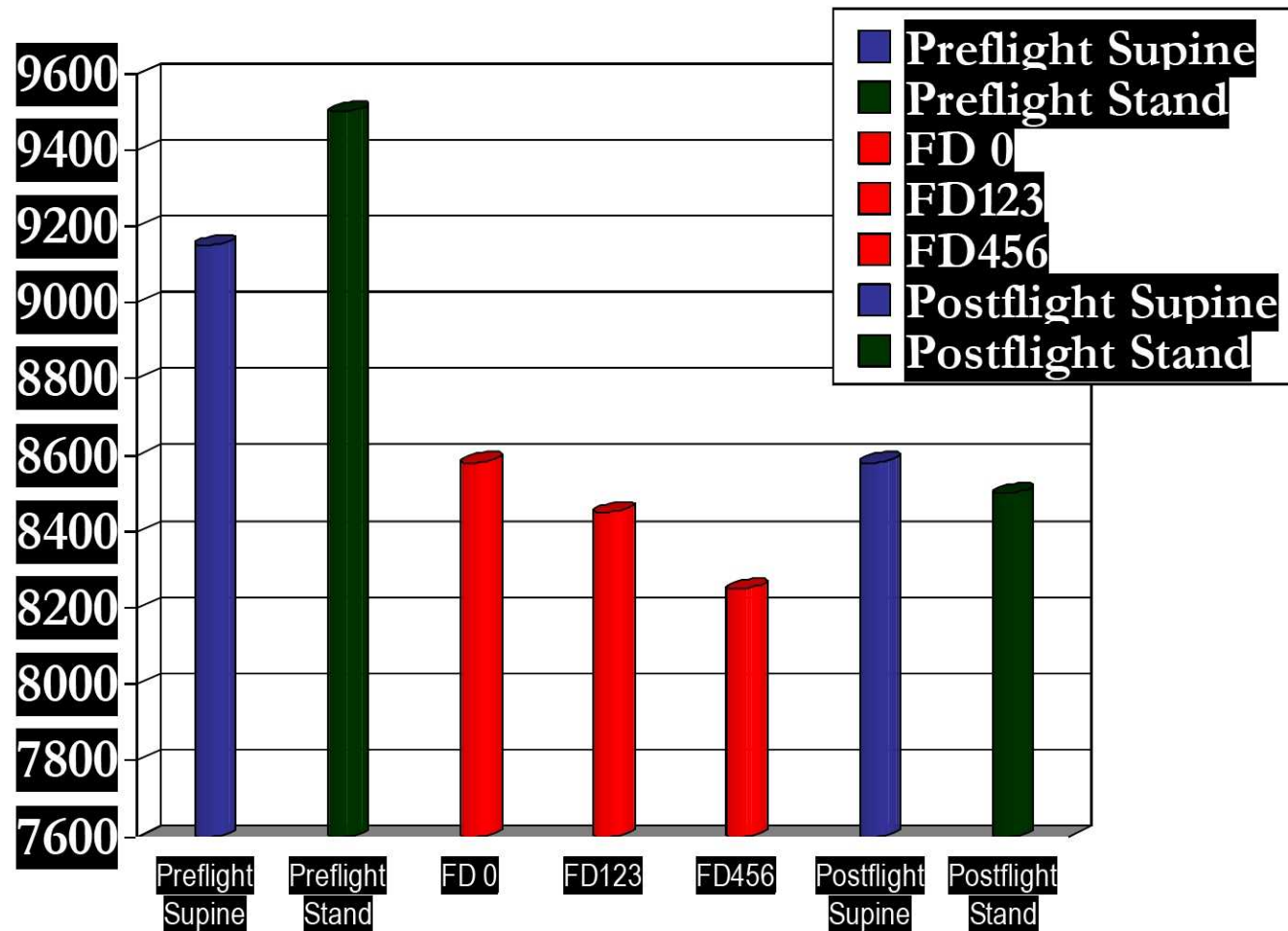
On Earth, gravity exerts a downward force to keep fluids flowing to the lower body.



The body rids itself of this perceived “excess” fluid. The body functions with less fluid and the heart becomes smaller.

Upon return to Earth, gravity again pulls the fluid downward, but there is not enough fluid to function normally on Earth.

Total Leg Volume Measurements



Fluid Shift:

“Puffy Head-Bird Leg Syndrome”

- Lack of gravity-no downward pull of fluids
- Fluids make headward shift
- Feeling different
 - Less Thirsty
 - Urinate frequently
 - Stuffy nose
 - Dull sense of taste
- Looking different
 - Puffy face
 - Thin legs

Effects on the Heart:

In-Flight Post-Flight

- Deconditioning effects
 - Decreased maximum power outputs during exercise.
 - Oxygen uptake less during exercise
 - Less circulating blood volume upon return to Earth
 - Decreased standing blood pressure

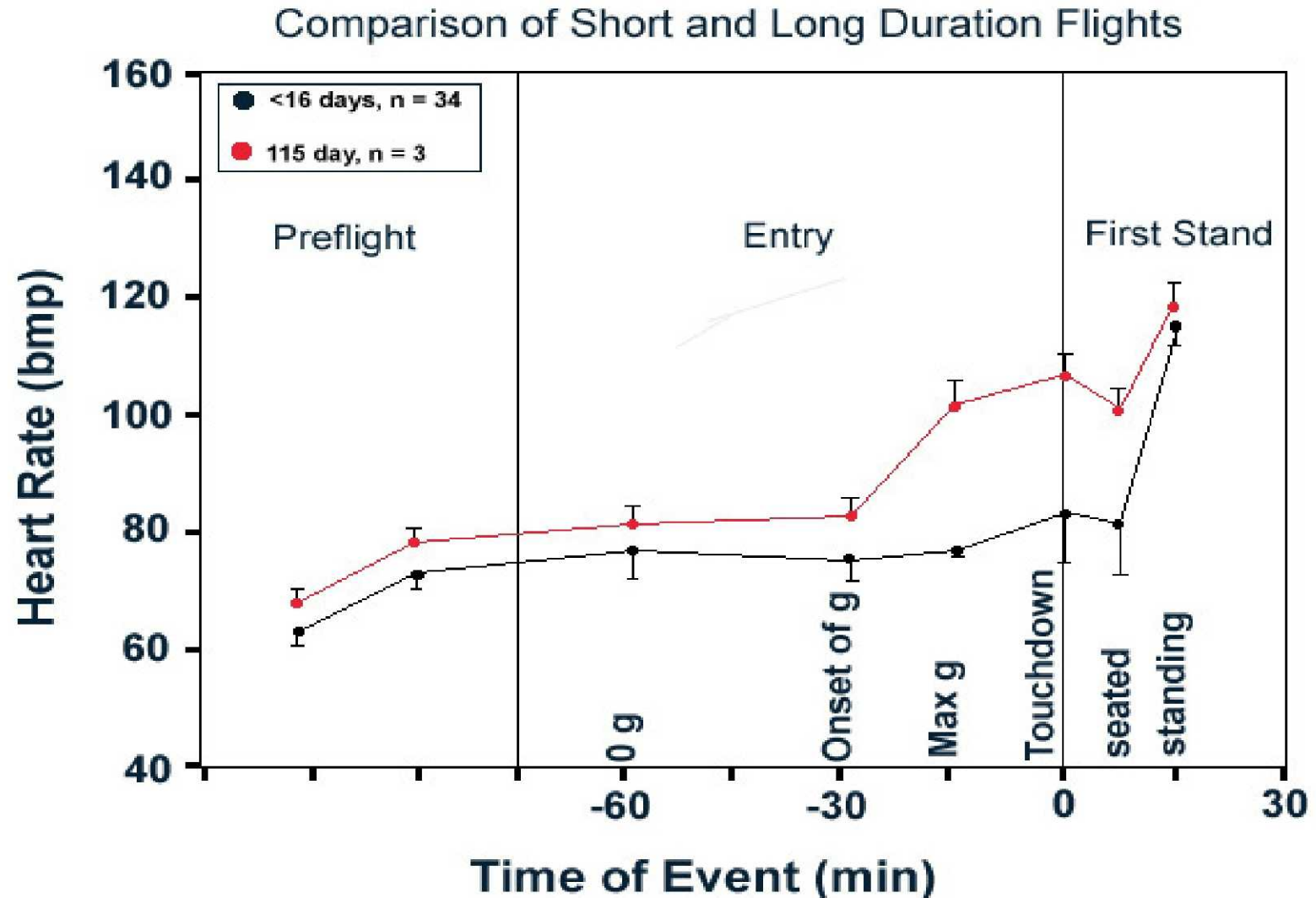
Thoynton WE, Hedge V, Coleman E, Uri JJ, More TP. ***Changes in leg volume during microgravity simulation.*** Aviation, Space, and Environmental, 1992.

Post-flight

Changes in the heart, vascular reflexes, and redistribution of body fluids during flight strongly predispose crew to *orthostatic* symptoms post flight

- **Incidence** — 20-67% of crewmembers
- **Symptoms** - Dizziness, lightheadedness, “gray out”, fainting
- **Time course** - From reentry to several hours postlanding
- **Causes**
 - Fluid shifts superiorly
 - Baroreceptor - endocrine - diuretic response
 - Impaired Vestibulosympathetic reflex?

Heart Rate Response to Landing



Countermeasures

- **Cardiovascular**
 - G-suits and Liquid Cooling Garment
 - Exercise
 - Medication

Countermeasures to Fluid Shift for 1g Re-adaptation

- Fluid Loading
 - 1 Liter water with 2-8
1-gram salt tablets
 - Chicken Consumier
 - Gatorade-like drink

Musculoskeletal

Changes in antigravity muscles, bone and calcium metabolism

- **Incidence** - All crewmembers are affected
- **Symptoms**
 - Acute - short term
 - Back pain (70% incidence on orbit to some degree)
 - Fatigue (less flexibility and endurance)

Musculoskeletal

- **Acute-**
 - Postural change with stretching of tendons and ligaments.
Increase in on-orbit height by 2-6 cm

Musculoskeletal

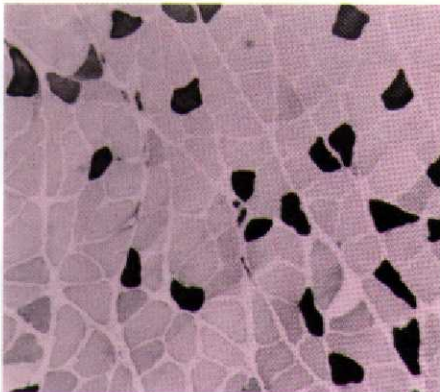
Chronic-

- Muscle atrophy
- Skeletal changes and loss of total body calcium have been noted in both humans and animals exposed to microgravity from 7 to 237 days.

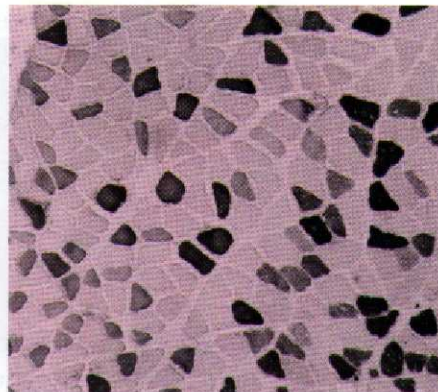
Nicogossian AE. *Space Physiology and Medicine*, 1989. Lea and Febiger, Philadelphia
Baldwin KM, Herrick RE, McCue SA (1993). *Substrate oxidation capacity in rodent skeletal muscle: effects of exposure to zero gravity*. J. Appl. Physiol. 75(6): 2466-2470

Effects of Spaceflight on Muscle

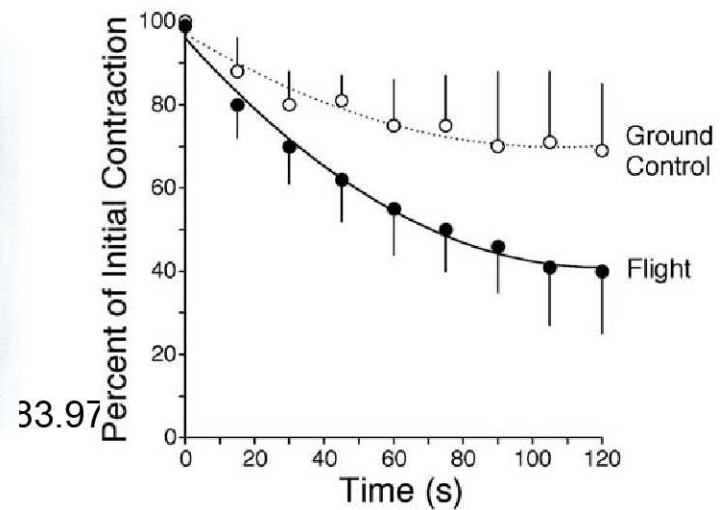
- Decrease in **body mass**
- Decrease in **leg volume**
- Atrophy of the **antigravity** muscles (thigh, calf)
 - decrease in leg strength
 - **extensor** muscles more affected than flexor muscles
- Data in flown rats showed an increase in number of **Type II**, “fast twitch” muscle fibers (those which are useful for quick body movements but more prone to fatigue)



Ground control



Flight



Musculoskeletal

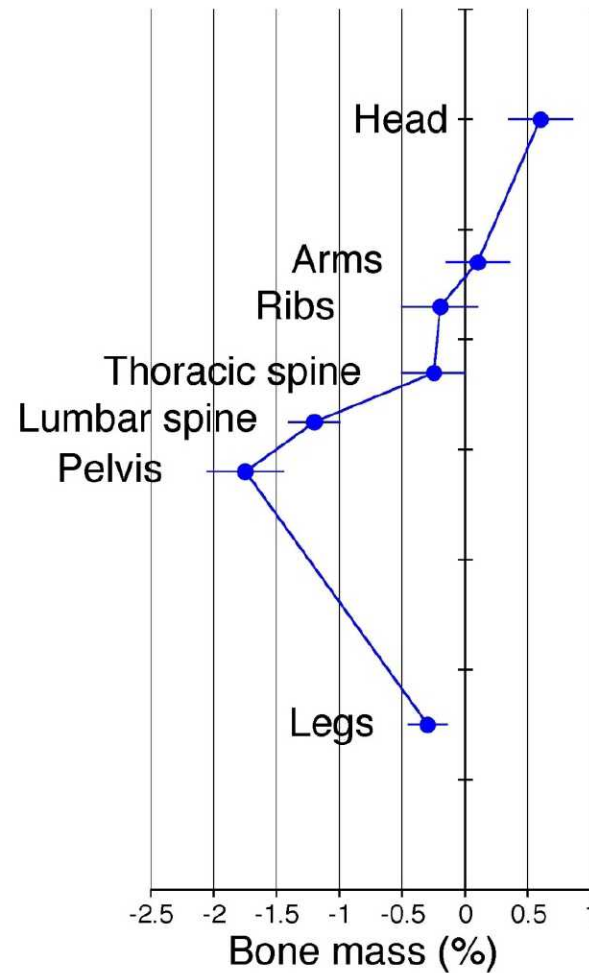
- Chronic –
 - Decrease in weight bearing causes muscle atrophy and bone demineralization, 1% - 2.4% per month in lower extremities and spine, with increased urine and fecal calcium
 - A direct effect of microgravity is the loss of mechanical stress on the skeletal system

Konieczynski, D. D., Truty, M. J., and Biewener, A. A. *Evaluation of a bone's in vivo 24-hour loading history for physical exercise compared with background loading*. J Orthop Res 16; 1998, 29-37

Bone Loss during Spaceflight

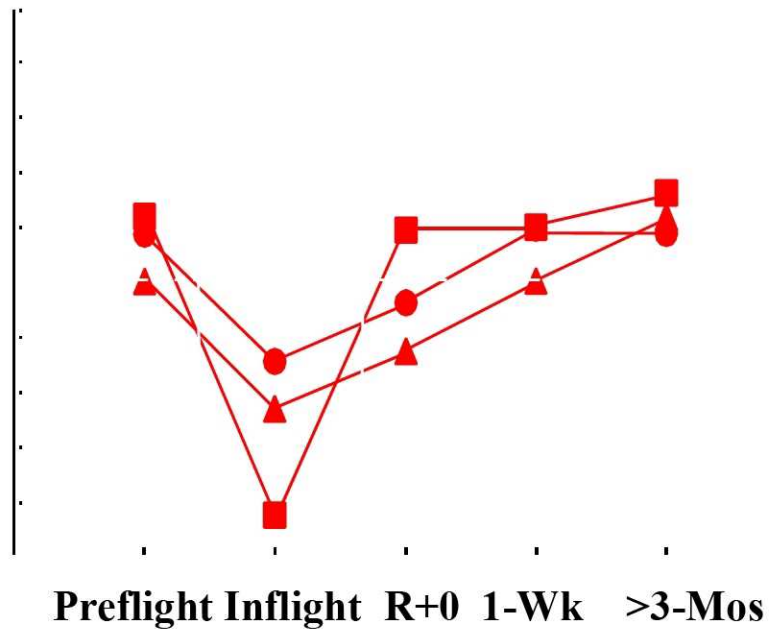
- Vostok: Increased fecal and urinary calcium first noticed
- Gemini: Loss of approximately 2-4% of bone mass in heel after 4-11 days of spaceflight
- Apollo: 3-5% decrease in bone mass after 10 days
- Soyuz: 8-10% decrease in bone density
- Skylab: 1-3% per month loss in bone mineral
- Mir: 10% loss of trabecular bone from lumbar spine in one cosmonaut after a 1-year mission
- Shuttle-Mir:
 - With countermeasures: 5.4% decrease in bone density in tibia. Did not return to preflight level in some individuals
 - Without countermeasures: 1.3-1.5% **per month** decrease in bone density (worst case: 15-22% total in some bones)
- ISS: Preliminary data similar to Shuttle-Mir

Bone Loss during Spaceflight



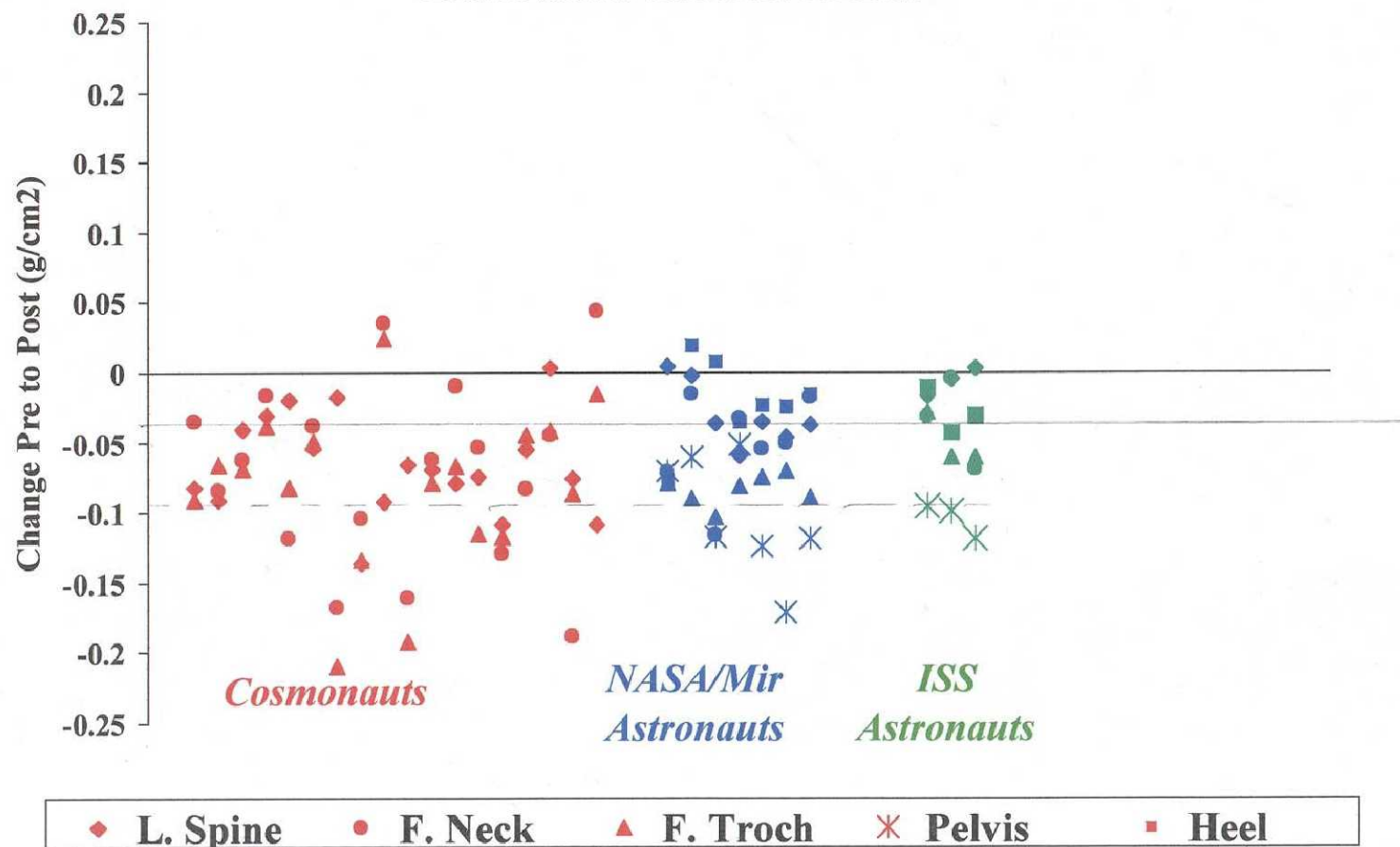
Bone Health Assessments

Bone Ca Balance ($V_{o+} - V_{o-}$)



Absolute Changes in Regional BMD

Cosmonauts and Astronauts



Effects of Long duration space flight on calcium metabolism

- Kidney Stones
 - Due to increased urine and fecal calcium
- Possible fractures
- Disk Disease

Musculoskeletal System Loss and Potential Complications/ Countermeasures

- Treatment for Acute Symptoms
 - Stretching
 - Exercise
 - Penguin Suits
 - Fetal Position Sleep Strap
 - Medications: e.g. NSAID- Rx for discomfort

Musculoskeletal System Loss and Potential Complications/ Countermeasures

- **Countermeasures in Practice**
 - **For Muscular strength and endurance preservation**
 - Aerobic (TVIS, CEVIS) and resistive exercise (RED)
 - NAC and other supplements/pharmacologics
 - **For Reduced bone strength/ Increased Injury or Fracture Risk:**
 - 1) Resistive exercise hardware
 - 2) Pharmacologic- e.g. Bisphosphonates
 - **For Urinary Calcium Excretion- Risk of Calculi**
 - 1) Increased Fluid Intake (2-3L/day)
 - 2) Resistive exercise
 - 3) Pharmacologic- e.g. inhibitor K^+ Citrate or K^+Mg^+ Citrate
 - 4) Contingency Management Strategy
- **Countermeasures under consideration/ preparation**
 - 1) Artificial gravity in transit
 - 2) PTH, Peptides

Exercise Countermeasures

In-Flight

TVIS

- Treadmill
 - Neurovestibular
 - Cardiovascular
 - Musculoskeletal
- Cycle Ergometer
 - Cardiovascular
- Resistive Exercise Device
 - Musculoskeletal

RED

CEVIS

Resistive Exercise Device (RED)

Countermeasures

- 2 daily 1-hour sessions of exercise:
 - Apollo Exer-Genie
 - Traction on “bungee cords”

Photos NASA

Immune System

- Depression of lymphocyte function affects at least 50% of space crew members
 - Decreased lymphocyte response to mitogens in cosmonauts after space flight was reported for the first time in the early 1970s by Soviet immunologists

Cogoli A. Space flight and the immune system. Vaccine. 1993;11(5):496-503.

Immune System

- Among the possible causes of space flight-induced alterations in immune responses are exposure to microgravity, exposure to stress, exposure to radiation, and many more as yet undetermined causes

Sonnenfeld G. The immune system in space and microgravity. Med Sci Sports Exerc. 2002 Dec;34(12):2021-7.

Hematopoietic system

- Reduction in Circulating Red Blood Cell mass
 - “Space Flight Anemia”

Udden MM, Driscoll TB, Leach-Huntoon CS, Alfrey CP. ***Decreased production of red blood cells in man exposed to microgravity.*** New England Journal of Medicine, 1994.

Lawrence Rice, Clarence P. Alfrey. ***Modulation of red cell mass by neocytolysis in space and on Earth.*** Pflugers Arch- Eur. J. Physiol., 441 (Suppl):R91-R94, 2000.

Behavioral/Psycho-Social

- Changes in crew mood, morale, and circadian rhythm
- Incidence - Affects all crewmembers to some degree
- Symptoms - Fatigue and irritability
- Time course - Depends on flight plan
- Causes
 - Work load
 - Sleep habits and facilities; chronobiology
 - Crew personalities and “crew space”
 - Temperature
 - Noise
 - Odors
 - Atmosphere
 - Diet
 - Lack of family contact
- Treatment - Treat causes

Physiological Issues in Partial Gravity

- Apollo lunar crews adapted quickly to the 1/6g environment
 - Initial unsteady gait related to EVA suit CG issues **not** neurovestibular dysfunction
 - Forearm and upper extremity fatigue attributed to glove design
 - Inadequate sleep, dietary caloric intake experienced by most crewmembers
 - Other physiologic function (cardiovascular, bone) unknown
- SMS did not recur upon return to microgravity

Apollo

- Review of Apollo Documents
 - Mission medical debriefs
 - Flight surgeon logs
 - Mission commentaries
 - Mission reports
 - Lunar surface journals
 - Preliminary science reports
 - Apollo lecture series
 - Personal communications

Hazards of Space Flight

- **Space Environment**

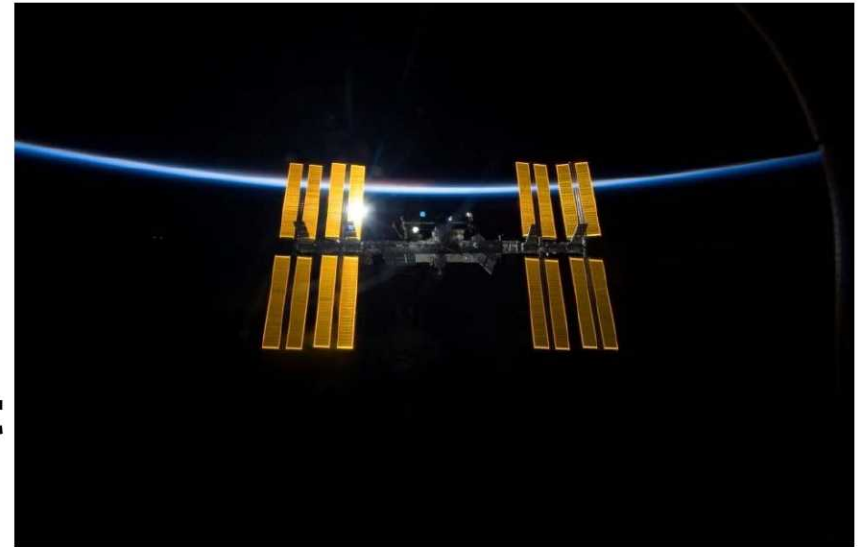
- Reduced Gravity
- Radiation
- Vacuum
- Debris

- **Space Craft Environment**

- Isolation and confinement
- Noise and Vibration
- Closed loop environment (life support)
- Payloads and construction activities
- Waste production

- **Space Flight Mission**

- Flight activity Launch and Reentry Forces
- Remoteness and communication access
- Circadian rhythms and crew schedule changes
- ExtraVehicular Activity (EVA)



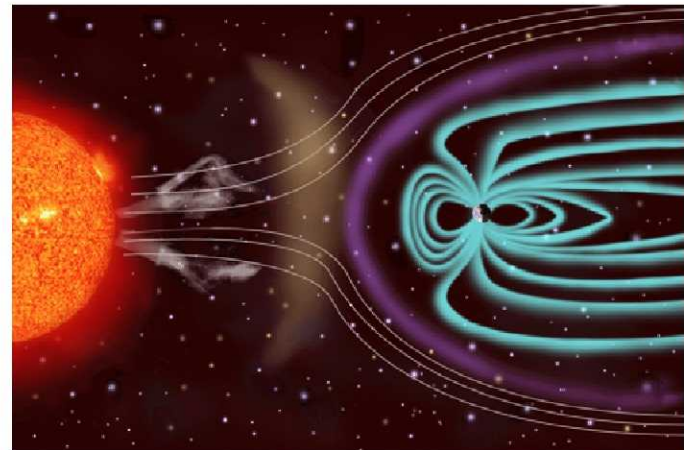
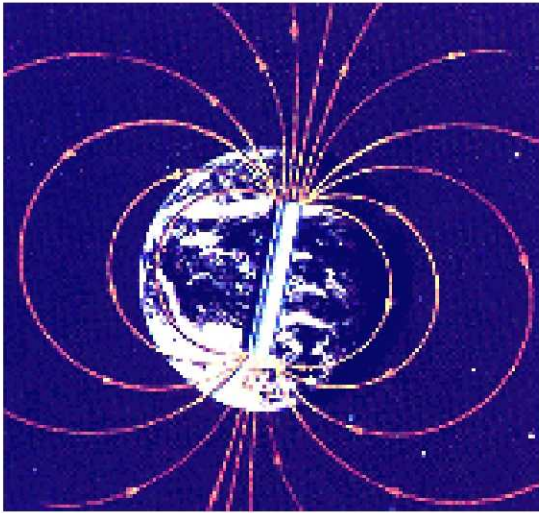
Space Flight Environmental Issues



STS069-347-013 (7-18 September 1995)

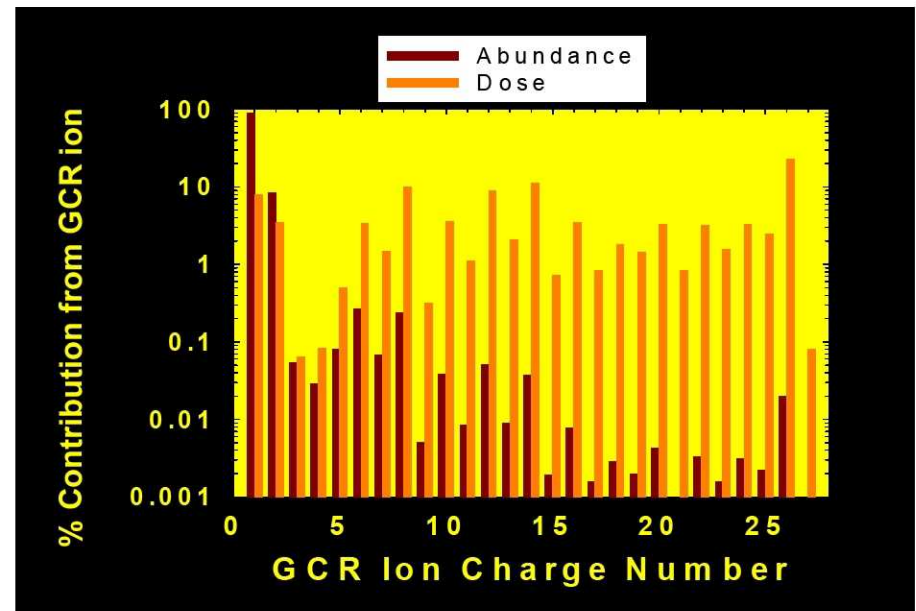
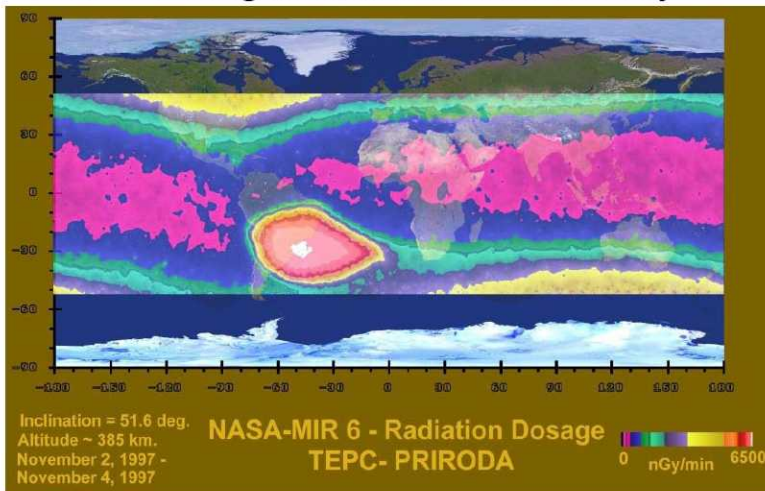
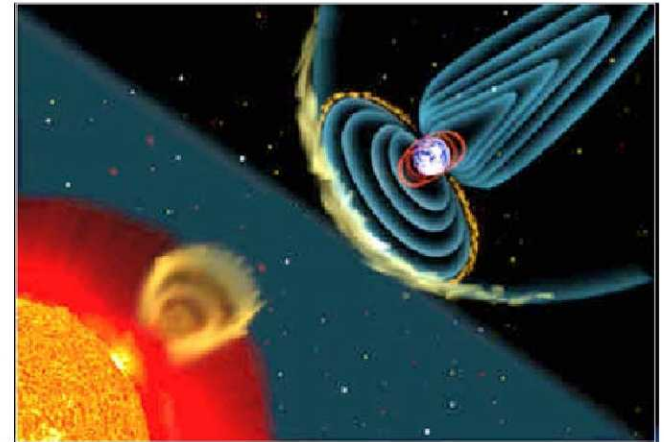
- Radiation
- Toxic products and propellants
- Habitability
- Atmosphere
- Medical events

Geomagnetosphere



Space Radiation Environment

- **Galactic Cosmic Rays (GCR):**
 - highly penetrating protons and heavy ions of extra-solar origin
 - large amounts of secondary radiation
 - largest doses occur during minimum solar activity in an 11-year solar cycle
- **Trapped Radiation in South Atlantic:**
 - medium energy protons and electrons
 - effectively mitigated by shielding
- **Solar Particle Events (SPE):**
 - medium to high-energy protons
 - occur during maximum solar activity



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Radiation

- Exposure based on orbital altitude/inclination, duration, and solar activity
- Crewmembers are radiation workers
 - Limits for mission and career exposure are set by the National Council on Radiation Protection
- As Low As Reasonably Achievable (ALARA) principle for mission planning
- Exposure monitored by active and passive dosimeters

Biologic Effects of Radiation Exposure

- Immediate and Delayed Effects
 - **Direct**
 - Largest cellular target- Nucleic Acids
 - Lethal events (esp. if large track or clustered hits)
 - High, acute dose (overwhelm defenses, often lethal)
 - Chronic, low dose (mutations-cancers)
 - **Indirect**
 - Reactive Oxygen Species
 - Lipid Peroxidation
 - DNA Methylation

Sleep Station in US Destiny Lab

Water storage bags and HDPE

Toxic Products and Propellants

- **Possible crew exposure to generic and payload-specific compounds**
- *Surgeon works in conjunction with Toxicology, Payloads, and Life Support to clean the environment and remove hazards*
 - Fire, smoke, and toxic spill procedures
 - Quick Don Mask (QDM)
 - Compound Specific Analyzer - Combustion Products (CSA-CP) ; Monitors O₂, CO, HCl, and HCN
 - Air sample bottles (analysis post flight only)
 - Contaminant Cleanup Kit (CCK)

Habitability

- **Noise-** Upper limit of 74 decibels (average) per 24 hours
- **Temperature-** Hot cabin $\geq 90^{\circ}$ F with 90% humidity
- **Water-** Quality tested for iodine levels, microbes and pH at L-15 days and L-3 days
- **Waste-** Apollo bags and urine collection devices as backups to the waste collection system

Atmosphere

- **Hypoxia**
 - Decreased oxygen
 - Cabin pressure leak
- **Hypercapnia**
 - Increased carbon dioxide
 - Failure of air revitalization system (LiOH canisters)

Atmosphere

- **Decompression sickness**
 - Reduced pressure releases nitrogen bubbles into blood and tissues
 - Symptoms range from joint pain to unconsciousness
 - **Prevention**
 - Adequate prebreathe of 100% O₂ that lowers N₂ pressure in decompression stages
 - **Treatment**
 - Repressurization
 - Aspirin
 - 100% O₂
 - Bends Treatment Apparatus (BTA)
 - Fluids
 - Hyperbarics (ground-based)

Other Environmental Issues

“Those that do not read and understand history are doomed to repeat it”

– President Harry S. Truman

- **Apollo 1 fire**
 - 100% oxygen at sea level pressure
 - Lack of materials control
- **Apollo 13**
 - Critical consumables location
 - Multiple hardware developers
 - CO2 removal
- **Shuttle, Shuttle/Mir, ISS experiences**

Lunar Dust

Why are we concerned?

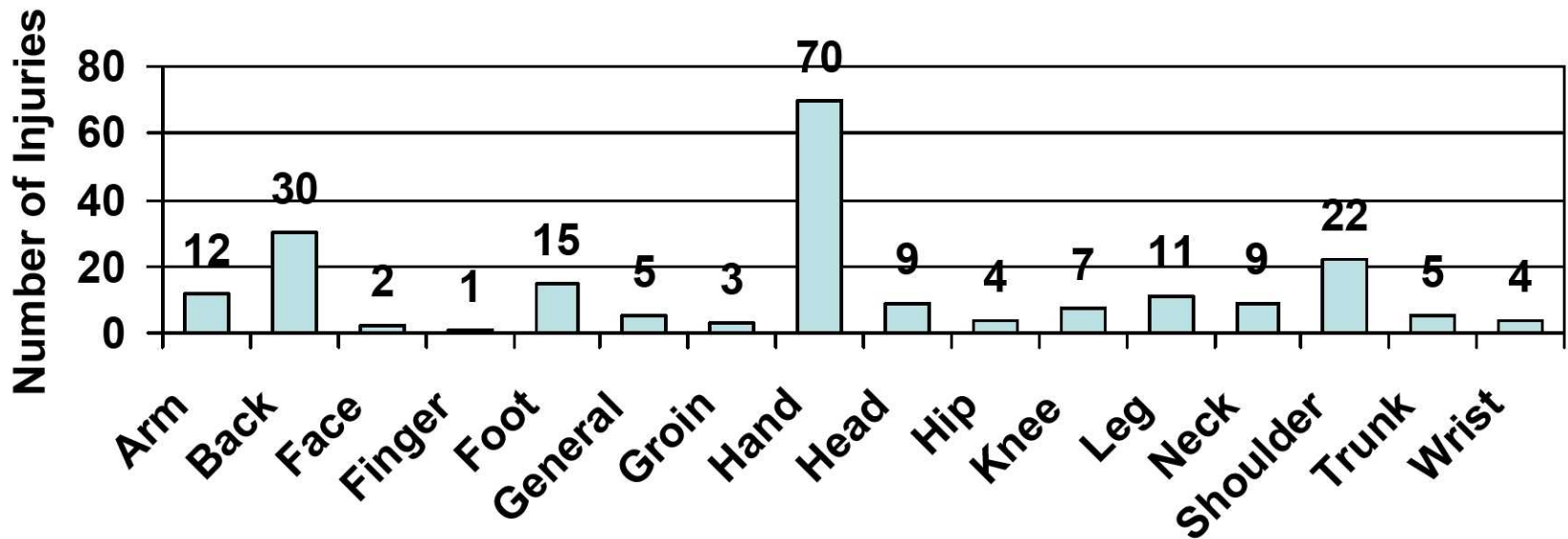
- Dust particles levitated at the lunar terminator, perhaps due to polarity changes (Criswell '72). 0.16 G at lunar surface, where there is a layer of fine particles that are easily disturbed and placed into suspension. These particles cling to all surfaces and pose serious challenges for the utility of construction equipment, air locks, and all exposed surfaces (Slane '94)
- After lunar EVA the crewmen and the samples they had collected were covered with fine lunar material. Despite attempts at clean-up and packaging in the LM, transfer of crew and materials back to the CM resulted in contamination of the CM atmosphere (Brady et. al, 1975)
- Apollo astronauts were not in the lunar environment long enough to develop the clinically significant, dust-related symptoms. However, during upcoming missions, crews will be on the Moon for months at a time.
- Properties
 - Size, shape, lack of weathering
 - Possible reactivity- volatiles, solar protons

Medical Events

- Focus is prevention of illness, infection, pain
- Can support life threatening emergency, to some degree
- Medical care is provided by Shuttle Orbiter Medical System (SOMS) or Crew Health Care System (CHeCS) for the Int'l Space Station
- Surgeon is responsible for training the Crew Medical Officers (CMO) – two per crew

In-flight Musculoskeletal Injuries in the US Space Program

Fig. 1. In-flight Musculoskeletal Injuries Throughout the U.S. Space Program by Location



Medical Events in Russian Space Program

Events that did not result in mission termination or early return:

- Spacecraft fires - 1971, 77, 88, 97
- Kidney Stone - 1982
- Hypothermia during EVA - 1985
- Psychological Stress Reaction - 1997
- Spacecraft depressurization - 1997
- Toxic Atmosphere - 1997

In-Flight Health Impact Events

- **Medical Evacuation**
 - 3 Russian medical-induced vehicle evacuations
- **Near misses**
 - Cardiac event on-orbit, Heart Attack 6 weeks post-flight
- **Medical with mission impact**
 - Apollo 13 – Kidney infection during mission
- **Neurologic consequences of Spaceflight**
 - Impaired cognitive performance aka “Space Fog” or “Space Stupids”
- **Behavior and performance**
 - STS payload specialist despondent when payload experiment failed, crew concerned about potential for dangerous behavior
- **Medication events**
 - Excessive medication use prior to EVA
- **Fouled Atmosphere**
 - Fire, toxic release, etc.
- **Thermal Issues**
 - Hyper- and hypo- thermia

Medical Events in Flight – Medical with Mission Impact

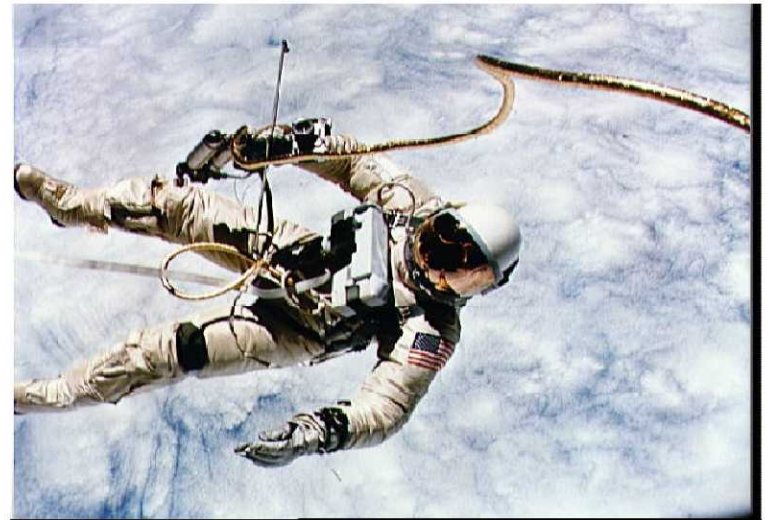
- Apollo 9 - EVA rescheduled due to motion sickness
- Apollo 11 – Type 1 DCS in command module pilot
- Apollo 13 – Kidney infection during mission
- Apollo 15 – Cardiac irregularity during lunar EVA
- Apollo Soyuz Test Project – Nitrogen Tetroxide leaked into capsule on reentry, crew hospitalized post-flight for chemical pneumonitis
- ISS - Crewmember pulled from EVA due to cardiac abnormalities

Apollo Lunar Surface Musculoskeletal Events or Minor Trauma^{1,2}

- **9 Events were reported on the lunar surface related to EVA**
 - 5 events located in the hand
 - Muscle fatigue during lunar EVA related to activities in the glove (unscrewing core tubes, etc.)
 - Finger soreness attributed to high work load
 - MCP, distal phalanx pain, swelling and abrasions after lunar 3/3 EVA
 - *“Completing a subsequent EVA would have been very difficult on account of how sore and swollen my hands were”*
 - 2 events occurred in the wrist
 - Wrist laceration due to suit wrist ring cutting into skin
 - Wrist soreness where suit sleeve repetitively rubbed on surface
 - 1 event resulted in shoulder strain after EVA 2/3
 - Crewmember injured shoulder during surface drilling activity
 - Required large doses of aspirin to relieve pain
 - 1 event described as general muscle fatigue while covering large distances by foot on the lunar surface

Health Risk during EVA

- Separation from spacecraft
- Micrometeoroid/ orbital debris (MMOD)
- Foreign body Injury (inhalation, ocular)
- Worksite injury (crush, electrical)
- Contact with Toxic Substances
- Hypobaric space suit pressure
- Life Support System failures
- Suit leaks in Vacuum
- Thermal Injuries
- Light Glare/ Darkness
- Radiation



EVA Physiological events

EVA anecdotes:

- EVA-STS blind due to eye irritation (drink bag leak with helmet) anti-fog solution drops for several minutes (may have been up to 5 minutes)
- EVA improper boot fit causing severe pain during EVA, with skin breakdown
- Vomiting in EMU (happened when crew back in airlock-beer and jalapenos not the best idea before EVA...)
- Toxic exposure to EMU suit (NH₃ coolant line leaked and sprayed crew member) had to do decon outside and bake off in sun
- EVA suit visor steamed up
- EVA suit rip and crew developed sunburn
- Rotator cuff tear (Multiple training associated upper extremity injuries)

EVA Suit Trauma

- Existing Space Suits cause significant trauma to crew members
 - Oncholysis-Finger nail damage
 - Shoulder and other orthopedic injuries
 - Bruising, abrasions, parathesias
- Minimize movement and point loading within suit
- Ensure suit kinematics are designed in conjunction with human biomechanical considerations
- Lower operating suit pressures
- ? Form-fitting, inflate to fit LCVG

Exploration EVA System

Key issues



- Improving the Work Efficiency Index (EVA time/Overhead time)
- Selection of habitat atmosphere and suit pressures
- Control of suit pressure, weight, kinematics and center of gravity (cg)
- Control of suit/crewmember biomechanical interactions to minimize suit induced trauma

Medical Care in Space

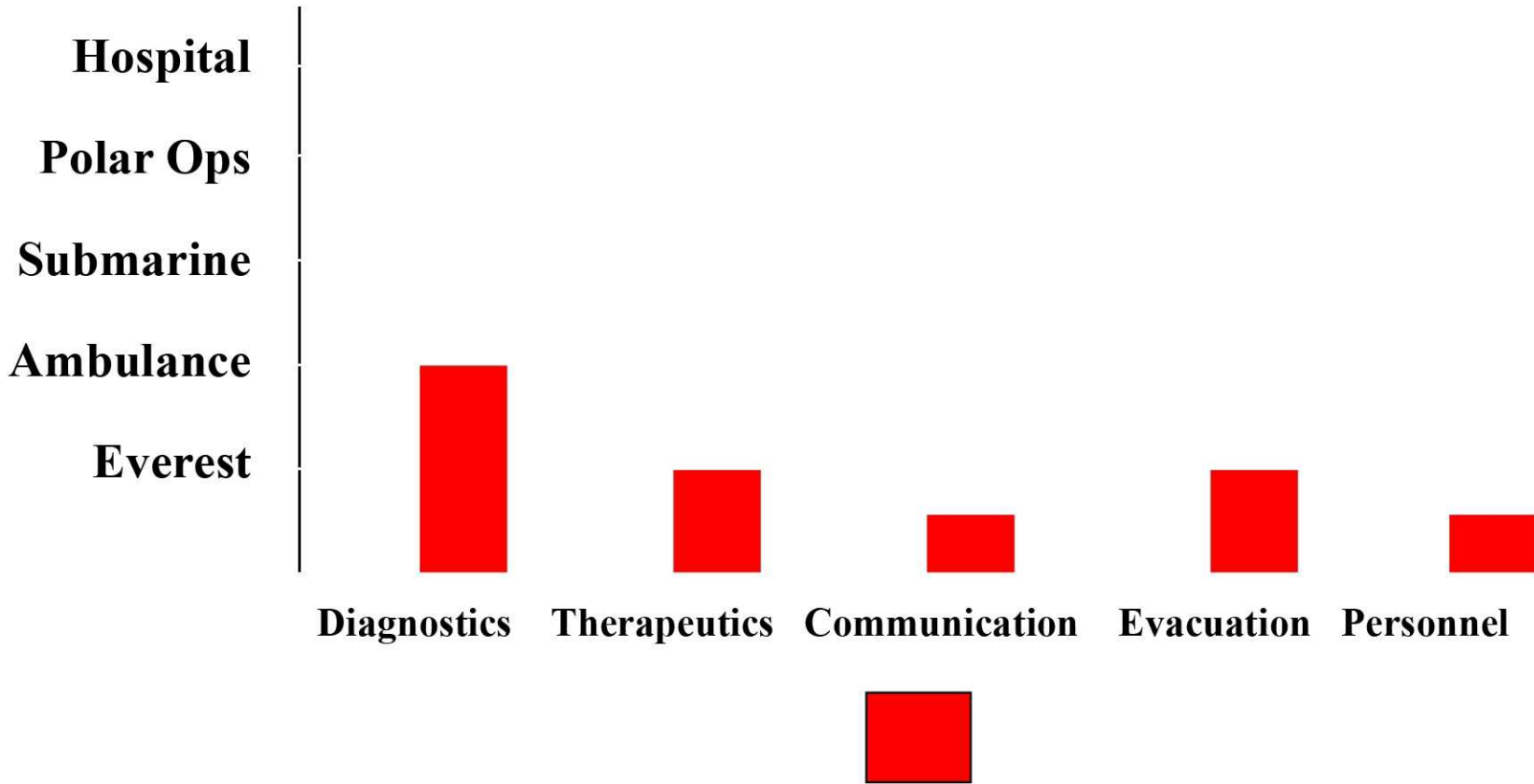
Although human physiology is altered by exposure, particularly long term exposure, to microgravity, basic metabolic and physiologic processes remain largely unchanged



Vs.



ISS Medical Capabilities Comparison



Diagnostic Capabilities

Medical Care in Space

- Crew Medical Officer (CMO)
 - Limited training
 - Air-to-ground communication limits
 - Limited resources
- MCC Flight surgeon
 - Limited time to “work the problem”
 - Requires evidence-based resources within arms reach



“ALL”

- Autonomous
- Light (modular)
- Lean



Shuttle Orbiter Medical System (SOMS)



13 July 2009

R.A. Sch

Space Medical Issues- Future



- **Expected illnesses and problems**
 - Orthopedic and musculoskeletal problems
 - Infectious, hematological, and immune- related diseases
 - Dermatological, ophthalmologic, and
 - ENT problems
- **Acute medical emergencies**
 - Wounds, lacerations, and burns
 - Toxic exposure and acute anaphylaxis
 - Acute radiation illness
 - Dental, ophthalmologic, and psychiatric
- **Chronic diseases**
 - Radiation-induced problems
 - Responses to dust exposure
 - Presentation or acute manifestation of nascent illness

Medical Concept of Operations for Exploration (CONOPS)

Our mandate:

- 1. Keep the mission going*
- 2. Maintain healthy/functional crew*



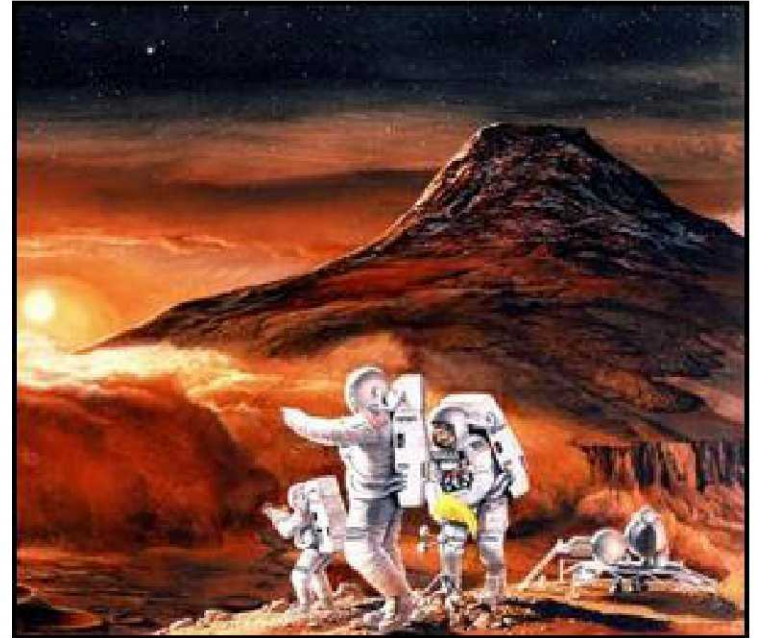
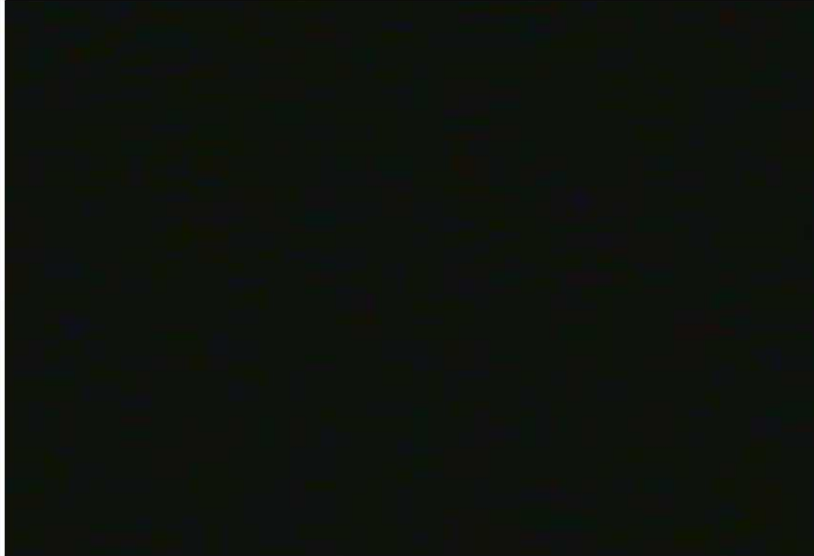
Guiding Philosophy: Prevention; Prevention; Prevention (with a little Prophylaxis mixed in)

- **Revised selection and mission medical standards**
- **Improved pre-flight medical readiness program**
 - Fitness
 - Optimization of health
 - Crew rest???
- **Better system design to reduce crew overhead**
 - Reduce fatigue
- **Emphasis on safety**
 - Vehicular components
 - Mission Planning, esp. EVA
 - Flight Rules
- **Maintenance of Performance**
 - EVA
 - Re-entry
 - Recovery



Mission to Mars

What do we need to do
to go to the Moon and
Mars and come back
home?



Links

- <http://spaceflight.nasa.gov>
- <http://liftoff.msfc.nasa.gov>
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